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## **GonioExp06 - A field goniometer intercomparison campaign, in support of physical model inversion and upscaling methods for hyperspectral, multispectral RS data**

Schneider, Thomas ; Schopfer, Jürg ; Oppelt, Natascha ; Dorigo, Wouter ; Vreeling, Willem ; Gege, Peter

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## - GONIOEXP06 -

### A FIELD GONIOMETER INTERCOMPARISON CAMPAIGN, IN SUPPORT OF PHYSICAL MODEL INVERSION AND UPSCALING METHODS FOR HYPERSPSCTRAL, MULTIDIRECTIONAL RS DATA

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#### ABSTRACT

The GonioExp06 field campaign from 19<sup>th</sup> to 24<sup>th</sup> of June 2006 is part of a strategic initiative to improve bio-geo-chemo-physical parameter estimation from optical remote sensing data. The focus of the research is on the investigation of the directional fraction of hyperspectral data, emphasising the value adding effect of directional information as supplement to the well known spectral one. Three field goniometric systems (FIGOS, MGS and AISAgon) of different design, an extensive accompanying measurement campaign and simultaneous multidirectional data taken by Proba/CHRIS (space) and ROSIS (airborne) are combined to create the data base necessary to investigate the radiative transfer between the surface and the sensors and to contribute improving physical modelling and inversion techniques. The application focus is the “precision” domain in land use (agriculture, forestry, nature conservation).

**Keywords:** field goniometer, accompanying measurements, BRDF, physical modelling, radiation transfer, up- downscaling, Proba/CHRIS, ROSIS

#### 1. BACKGROUND AND MOTIVATION

Almost all natural surfaces exhibit individual anisotropic reflectance behaviour. The underlying concept which describes the reflectance characteristic of a specific target area is called the bidirectional reflectance distribution function (BRDF) and depends on the illumination and observation directions [1]. The BRDF of known surfaces is an essential component of RS data normalization concepts (e.g. ATCOR3, 4)[2]. The retrieval of bio-geo-chemo-physical parameter from

air- and spaceborne scanner data requires radiometric corrections accounting for sensor, atmospheric, topographic, illumination and cross track effects.

The availability of multi-directional data sets from multi-angular systems like PROBA/Chris, MISR, from on-track stereo systems like Spot-5, ALOS/Prism, and airborne systems like HRSC, ADS, ROSIS opens an additional prospect, the evaluation of *angular signatures*. Angular signatures superimpose the spectral signatures (error source), but, rooting in structural surface features like roughness, leaf area distribution, etc., angular signatures are a mostly uncorrelated information source, expected to complement the spectral signatures in bio-geo-physical parameter retrieval. The angular signature is not sensitive to bio-chemical parameter. The BRDF of identified surfaces is the key to assess and interpret angular signatures. Field goniometer systems are developed to provide the directional measurement sets required for BRDF approximation.

GonioExp06 was designed to investigate the information chain between vegetated surfaces and data retrieved from multidirectional, multi- and hyperspectral RS data using physical model inversion methods. Previous investigations on illumination to observation effects in the diurnal cycle [3] [4] using two different systems for directional measurements, the Mobile Unit for Field Spectroradiometric Measurements (MUFSPeM) [3] and the Mobile Goniometric System (MGS)[4] revealed differences in parameter retrieval of an magnitude which is not acceptable. Main aim of GonioExp06 is to eliminate or at least quantify error sources identified during previous campaigns [5][4]:

i): *Errors due to the setup for directional measurements, measurement schemes or the instrumentation* are assessed by an intercomparison of field goniometer concepts on behalf of synchronous measurements of the same surface type, the crop "Triticale" and intercomparisons of the involved Field Spec instruments.

Three systems for directional measurement are involved: the Field Goniometer System (FIGOS)[6] of the RSL, University of Zürich, which is considered the reference system, the Mobile Goniometer System (MGS) of the Limnological Station of the TU München [5] and the AISA based hyperspectral imaging field spectrometer system (AISAgon) of the Remote Sensing Technology Institute (IMF) of the German Aerospace Center (DLR).

The time span for one measurement series being a critical variable an expected outcome is the establishment of a minimum view angle set for BRDF retrievals (one series and repetitions during one day).

ii): *Misinterpretations due to missing or erroneous accompanying measurements* as required to support RS data interpretation and to characterize the surface type under investigation are prevented by an extended data collection with two independent measurement methods for some bio-geo-chemo-physical parameter: cloud cover assessments using a hemispheric camera, direct/indirect radiation measurement with a MSR-7 sunphotometer, destructive and in situ measurements of the vegetation/soil complex (wet/dry biomass, water content, LAI and chlorophyll content with 2 methods, LAD).

The definition of a minimum data set of accompanying measurements needed to fully interpret the measurements achieved with field goniometer systems is envisaged.

iii): *Errors due to up- and downscaling issues* occurring by correcting air- or spaceborne data on base of BRDFs from data bases as described in [4][5].

To directly quantify such errors the BRDFs derived from field data are compared with simultaneous acquired ROSIS and Proba/CHRIS directional hyperspectral data. The direct comparison with should contribute to improve the basic understanding of the radiation transfer complex and especially of atmospheric correction programs for off nadir data, the field goniometer data. For this purpose ROSIS was firstly flown in the multidirectional data mode with  $\pm 17^\circ$  and nadir view geometries, both in the principal and the orthogonal plane.

iv): *Retrieval errors due to physical model adaptation:* in practice data takes at differing view geometries and illumination conditions have to be handled. Inversions results based on MGS data sets retrieved with the

radiative transfer model ProSailh in the diurnal cycle [4] and based on different view direction combinations [5] showed variations of up to 100%. Testing the retrieval success with data sets of the different ground, air- and space borne systems and the extended accompanying measurements acquired during GonioExp06, error sources should be constricted leading to an overall improvement of the physical model.

GonioExp06 field campaign was performed from the 19<sup>th</sup> to 26<sup>th</sup> of June 2006 at the Proba/CHRIS supertest site Gilching, Germany, center coordinates  $48^\circ 05' 25''$  N  $11^\circ 18' 47''$  E (Fig. 1).

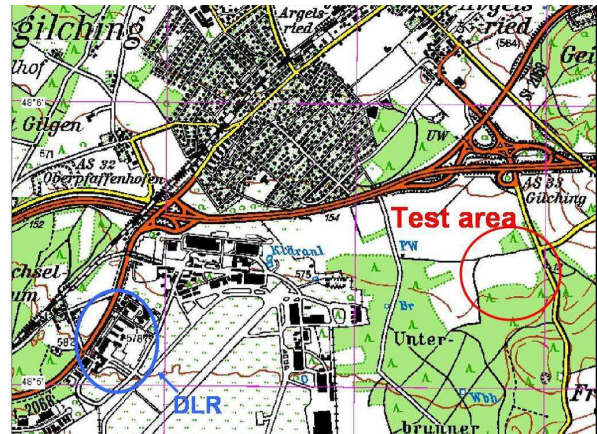


Figure 1: GonioExp06 test area Gilching

## 2. RESULTS (SOME OFF)

### 2.1 Field-spectro-radiometer intercomparison

The calibration of the FieldSpec instruments may be altered by aging of the detectors, fiber cables, dirt of the entrance optics (fiber ends, foreoptics), etc. but other effects as well. The intercomparison of the participating instruments should:

- Quantify the differences between the instruments (radiance, SNR)
- Deliver transformation functions allowing a comparison of the radiance values between the instruments
- facilitate an instrument exchange in case of bottlenecks during future campaigns
- Quantify the spectral and directional reflectance behaviour of the reference panels

For the intercalibration measurements it was possible to access the new ESA intercalibration facility at the DLR, offering a integrating sphere with the corresponding infrastructure for stable conditions [7].

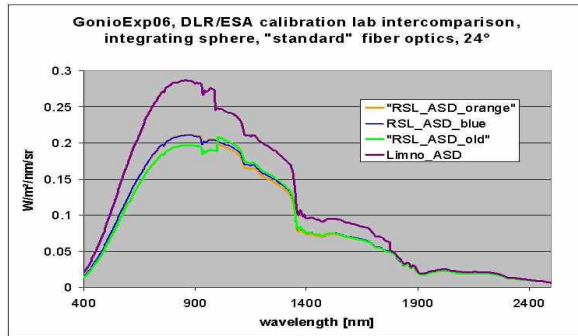


Figure 2: Intercomparison of FieldSpec instrument, bare fiber, 24° optic, radiance mode

The comparison of radiance data with the standard bare fiber and 24° optic of four of the five instruments show differences up to 30% (Limno ASD to the RSL ASDs) and an pronounced "parabolic effect" between the first and the second detector at around 970nm.

## 2.2 Concepts of the field goniometer systems

The primary aim of the field-goniometric campaign is the approximation of the bidirectional reflection distribution function (BRDF) of selected surface types at the given frame conditions during the measurements. By a direct comparison of three different designs for directional measurements in the field it was aimed to assess the approximation accuracy, resp. the variation due to the differing concepts. Within GonioExp06 the following questions are addressed:

1. Which aperture angle, which measurement height, which time span for one measurement series is considered to be optimal, which are the tolerable variations?
2. How many and which view angle sampling design are at least required for a BRDF approximation?
3. which homogeneity assumptions for the measured section are required regarding:
  - a. change of size due to view angle changes
  - b. different sections measured at each view angle
4. how many measurement series are necessary to resample the diurnal cycle?
5. Which concept for reference measurements is appropriate?
6. Which are the advantages of a biconical compared to a hemispherical-conical data take?

The LSPIM study [8] [9] recommend to take more measurements around the hot spot position and to reduce measurements in the fore ward scatter direction.

The European Goniometer Facility (EGO) at the Joint Research Centre in Ispra, the initial Field Goniometer System (FIGOS) from the RSL as well as the Mobile Unit for Field Goniometric Measurements (MUFSPM) are collecting directional reflectance measurements with differing time gaps between the reference and the object

measurement. Measurement series for BRDF approximations with these systems lasts for up to twenty five minutes. During this time span changing illumination conditions may occur affecting the measurements. A design requirement for the new generation of field goniometric systems was a synchronous reference and object measurements. During GonioExp06 three solutions are compared:

1. Two identical instruments for reference and object measurement operated synchronous (dual mode of the "new" FIGOS)
2. One instrument, alternating reference/object measurement (MGS)
3. The use of array CCDs shortening the time between reference and object series (AISAgon solution)

*Alternative 1:* : two identical instruments are used for reference and object measurement. The "new" FIGOS is operating with two synchronized Field Spec 3 instruments arranged to deliver measurements for the full BRDF retrieval according to [10].

From the conceptual point of view this solution seems to be the one with the most flexible design options. The constraints are given by instrument costs on one hand but by the assumption of two identical instruments on the other hand. Previous experiments with two Field Spek FR instruments during the BOKU campaign in 2005 [5] failed. The analysis of the reasons guided us to the conclusion that the individual settings of the two Field Spek FR instruments are too different and even an intercalibration do not allow a reliable combination of two instruments. Additional limitations are the costs for two instruments. The experiment design of the RSL group during the GonioExp06 measuring incoming and reflected radiation with a 3° foreoptic in the same axis but in opposite direction made an additional constraint obvious: around the hot spot the instrument measuring the incoming radiation is arriving the saturation. This observation opens again the discussion about the conversion of HDRFs to BRDFs. The HDRF seems easier to measure as while the instrument is optimized for white panel reference measurements.

*Alternative 2:* is either time consuming in case the view direction must be changed between reference and object measurement or is accepting a loss of signal intensity at increased SNR. The MGS system is accepting a signal loss to shorten the overall measurement time span for one series.

*Alternative 3:* The question arising at such a design is whether the imaged surface section can be assumed to be homogeneous. The negation of this basic assumption of the MUFSPM design [3] guided us to the development of the MGS goniometric device. On the other hand, the AISAgon concept is imaging the measured section allowing a verification of the homogeneity assumption. The fast and easy to handle



concept is a very strong argument of AISAgon, opening a couple of applications. The present limitation on the silicon detector range is not a fundamental one and overall, the question which wavelength have to be registered for the characterization of the backscatter properties of a surface is still open and has to be discussed in detail anyway.

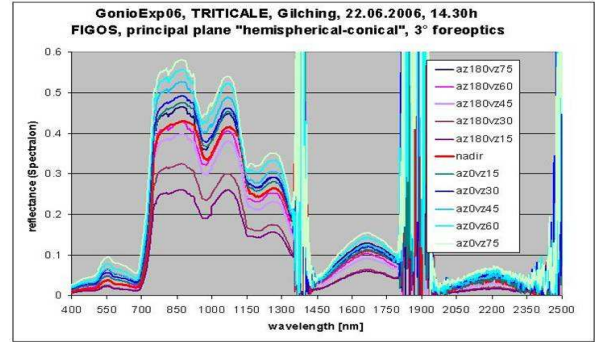
*Table 1: main characteristics of the measurements devices for directional measurements*

	FIGOS	MGS	AISAgon
positioning system	moving arc 2 ASD	inscribed angle ASD	fixed position
detectors	FieldSpek 3	Field Spek FR	CCD array
special design features	dual view	bifurcated fiber	rotating CCD array
height above surface	2 m	10 m	3 m (flexible)
FOV	3°	10°	8°, 23°
IFOV [°]	3°	10°	0.92mrad (23°)
GIFOV [m"]	0.01 to 0.02	1 to 1.1	<0.001 at nadir
azimuth range	1/1 hemisphere	2/3 hemisphere	programmable
vaz steps	30°	30°back, 45°fore	
vza steps	15°	20°	programmable
spectral range	350-2500 nm	350-2500 nm	418-896 nm
Spec. res.	2 - 10 nm	2- 10 nm	2 - 3 nm
views /serie	139	25	selectable
Time /serie	25 min	20 min	1 min
Pos. change	appr. 4 h	appr. 5 min	appr. 5 min

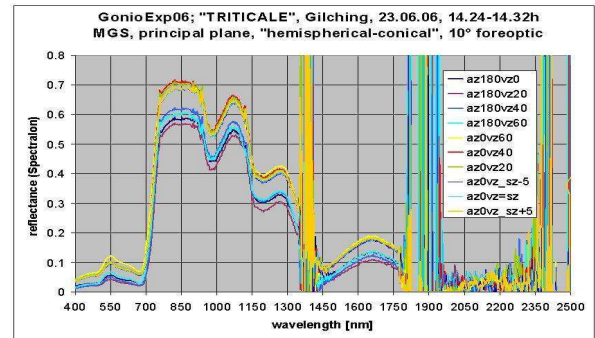
### 2.3 Results of the field goniometric measurements

Measurement series for BRDF approximation were planned at least during three daytimes: morning, at noon and in the evening. Solely the FIGOS work program was fully successful and delivered data sets for BRDF approximation (see [11] for a detailed description). MGS was immobilized by an assembling failure destroying the positioning electronics exactly at the day of the ROSIS overflights. Solely two measurements series on triticale and rape are available taken some days before during the system assembling tests. AISAgon is still not in a stage allowing operational measurements. Date sets on triticale and rape during the ROSIS data takes are available, the first results are promising, the calibration problem is not finally solved.

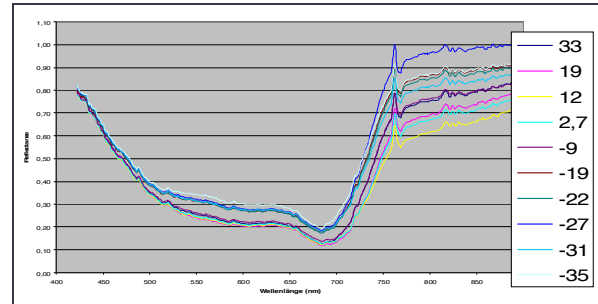
The Fig. 3 to 5 display HDRF spectra of the principal plane measurements from the three systems.



*Figure3: Principal plane HDRF spectra of Triticale calculated from FIGOS data for differing view zenith angles, 24.06.06, appr. 14.30h*



*Figure 4: : Principal plane HDRF spectra of Triticale calculated from MGS data for differing view zenith angles, 22.06.06, appr. 14.30h*



*Figure5: Principal plane HDRF spectra of Triticale calculated from AISAgon data for differing view zenith angles*

### 2.4 Accompanying measurements

Accompanying field data collection is mandatory for the interpretation of the spectral data and for the calibration of physical models. Doubts in the accuracy of such measurements let us apply more than one method for establishing some of the most important variables:

1. Chlorophyll content was measured in the laboratory at samples collected from the destructive measurement plots and by using a SPAD instrument. The lab chlorophyll measurements are

used for calibration of the SPAD results and can that fore not considered as independent methods..

2. Biomass was sampled destructiv at the testplots P1 to P9 and at the FIGOS measurement section. Separate data sets for stem, spikes, top leaf, second leaf, third leaf and biomass remains are available as fresh and dry matter values.
3. three different measurement methods for LAI determination: LICOR -2000 LAI-Meter, hemispherical camera imaging and destructive measurements on test plots P1 to P9 and the FIGOS measurement section
4. LAD was appreciated by field measurements and from portrait photographs
5. Coverage is appreciated by nadir photographs!

To support spectral data evaluations a sun photometer was operated the whole day and meteorological data were acquired from two meteorological stations of the German weather service (DWD). At the present solely the chlorophyll a+b and the biomass measurements are finished. LAI determination method for the destructive field samples is developed and applied to samples P1 to P4 and FIGOS. Examples are shown in the next subsections.

**2.4.1 Chlorophyll a+b asessment:** A laboratory leaf samples alysis field SPAD measurement method is applied to get an overview about the chlorophyll content of the Triticale field. Leaf samples were taken and immediately frozen in liquid nitrogen. The analysis of the chlorophyll content was carried out in accordance with the method described by [12] The photometric measurement was carried out using 80% acetone as blind value using a SOPRA DW 2000 photometer. The absorption was investigated using the wavelength 663.6nm for chlorophyll a and 646.6nm for chlorophyll b. show The correlation to the SPAD values retrieved from the whole Triticale field is good (Fig. 6).

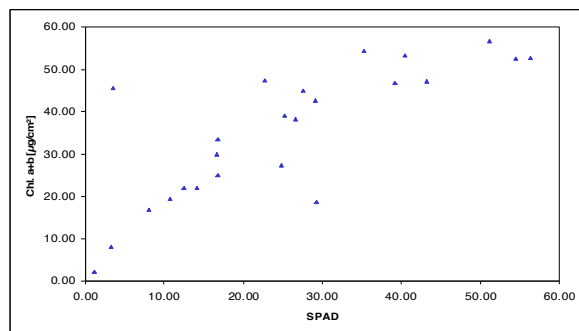


Figure 6: Laboratory measurements and SPAD values for chlorophyll a+b assessment

**2.4.2 Biomass determination:** Nine systematically distributed sample points supplemented by the FIGOS measurement area are sampled using a 25\*25 cm frame to exactly define the sample area. The material is

collected in plastic sacks and stored until measurement preparation at 4°C. For measurement preparation spikes, top leave, second leave, third leave, stem and remaining dry leave are separated in two more or less equal portions. The two top leave, two second leave, two third leave, two stem fractions, spikes, remaining biomaterial and the plastic sack are weighed separately. From the leave samples on portion is draped on adhesive foil with 2\*2 cm grid and scanned, respectively imaged by a digital camera. After scanning the leaves are again removed from the foil. All organ portions are dried at about 60°C for three to four days (>72 hours). After drying all portions are weighed again to obtain the dry biomass, resp. the transpired water captured in the sack during deposition. Water content is determined as the difference between fresh and dry weights. Finally the fresh biomass, the dry biomass and the water content is determined for the 25\*25 cm sampling area (Tab. 2).

**2.4.3 Leaf area determination:** The leaf area index (LAI) is one of the most important parameters for modeling. And thatfore assessed by three methods. The measured area using the leave samples as described above are used as reference for the indirect methods using the LICOR-2000 instrument and the hemispherical camera method. 127 foils are prepared from the samples, scanned and georeferenced with ENVI 4.2 on base of the 2\*2 cm grid of the adhesive foil. The \*.tif file data are than imported into eCognition 3.06 and processed in a two level hierarchical system using the protocol function of eCognition (Fig. 7).

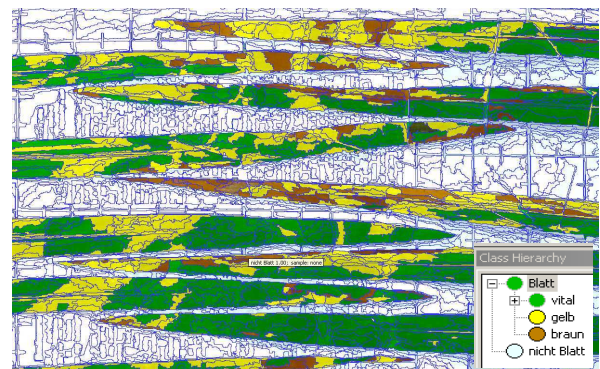


Figure 7: Class hierarchy and resulting eCognition classification on level 2

The resulting data set is delivering the number and size of the leaves on level 1 and the fraction of brown, yellow and green area in level 2. The LAI equivalent leaf area per square meter is calculated for level 1.

## 2.5 Status, preliminary conclusions, outlook

**2.5.1. Status:** The evaluation of the field goniometric measurements as well as of the Proba/CHRIS and ROSIS data sets is still in progress. Inversion attempts

are planned on behalf of the DLR /DFD imaging spectroscopy group by

Wouter Dorigo using ProSailh, at the RSL and at the IGGF as soon as all input data are available. Some questions to be addressed by these attempts are:

- Which illumination to observation geometries delivers the results closest to the accompanying measurement values?
- Do additional view geometries improve parameter retrieval?
- Is there a minimum number of view geometries required for a stable parameter retrieval?
- Which is the parameter value difference as retrieved by the tested models?
- Which additional information is mandatory which favorable?
- Etc.

**2.5.2. Conclusions:** GonioExp06 was a campaign driven by the interest of the participating scientists and *without any external funding!!* The drawback is that some evaluation steps are still not finished, some questions not answered. Obvious is the need for harmonization of nomenclature and the establishment of accuracy thresholds for such measurements. Again a couple of new questions arised, the task list for the next campaign was opened already during the running campaign.

**2.5.3. Outlook:** We are already discussing a follow on campaign and would encourage all interested researchers to participate. Especially we would encourage the modeling community to participate already during data take. Once completed the results gathered during GonioExp06 will be free available.

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